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Title:	Laser Interferometer Space Antenna (LISA) Launch 2034: how LANL can engage today
Author(s):	Meadors, Grant David
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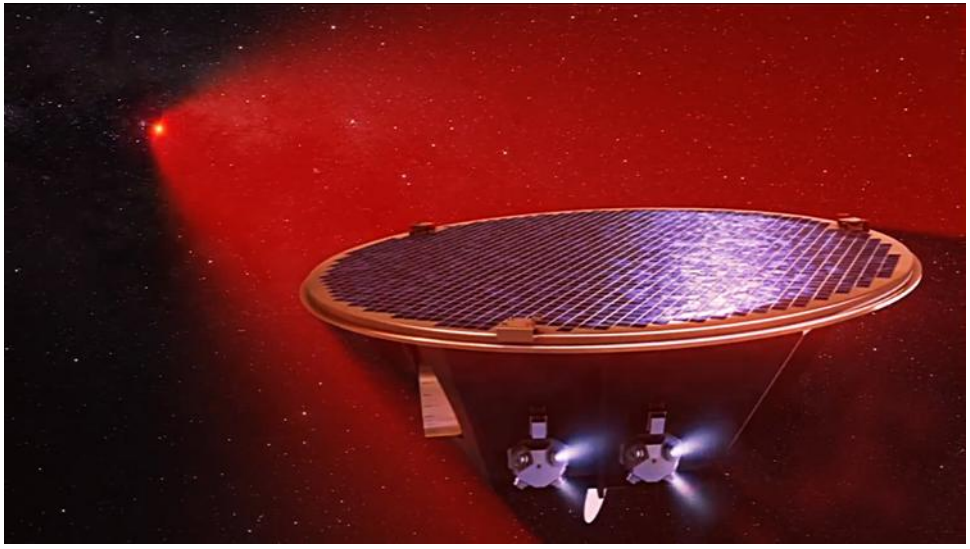
Laser Interferometer Space Antenna (LISA)

Launch 2034: how LANL can engage today

Grant David Meadors [he/him]
ISR-3, LANL

2021 July 01 (JD 2459397)
ISR-3 Brownbag Seminar Series

Preface



LISA:
L*aser*
I*nterferometer*
S*pace*
A*ntenna*
∴ ESA-NASA mission
will launch in 2034!

Artist depiction: one of 3 **LISA** satellites
in heliocentric orbit, receiving laser light
to measure distance interferometrically . . .
→ observing gravitational waves (GWs)
Credit: AEI/MM/exozet, via NASA

LANL in LISA Consortium ⟹ like telescopes, GWs reshape astro

Acknowledgment of country

I acknowledge the Tewa pueblo here at Otowi as traditional owners of this land, from where I speak, and pay respects to their elders, past, present, and emerging.

Background photo: LIGO Hanford Observatory. Credit: GDM

Outline

Today's Brownbag:

- Who I am
- What is a gravitational wave (GW)?
- Where LISA fits
- Why LISA benefits LANL
- How you can get involved

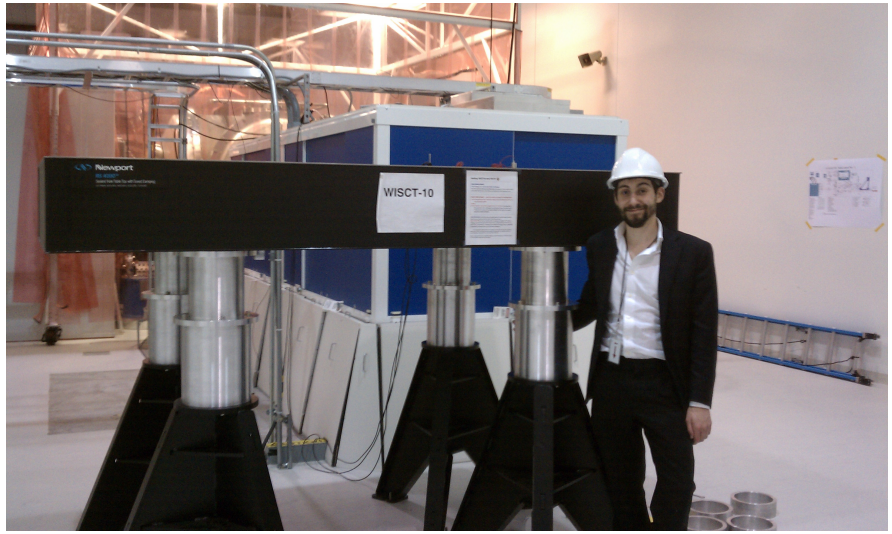
Introduction

Who I am – detector characterizer/data analyst – (astro)physicist

∴ 2008 to 2019 LIGO (Laser Interferometer Gravitational-wave Observatory)
∴ PhD: UMich 2014 (Physics)
+ postdocs:

1. AEI Hannover 2015/2017
2. Monash 2018/2019
3. XCP-8 2019/2020

∴ ISR-3 Scientist (Dec 2020-)



GDM at LIGO Hanford Observatory, 2011, procuring optical table extensions for quantum-vacuum squeezer

Kip/Rai/Barry's 2017 Nobel was great, . . . "new era of astronomy" but ground-based GW science only part of astrophysical spectrum

Introduction

$>$ ‘40000 foot‘ summary $\sim$ more like ‘orbital’ summary

Telescopes see light from stars + hot matter (EM radiation)

LIGO sees light (w/ interferometer),
– imprints GW signal from black holes (or neutron stars)

LISA like LIGO, but in space & BIGGER,
– bigger, slower GW signals from bigger black holes

Introduction

The story so far

LANL has no [official] LIGO group, *but*
some adjacent research benefits program!
Dingus (P), Fryer (CCS), Fontes (XCP), Li (T),
Mottola (ex-T), Vestrand (ISR-2), Wozniak (ISR-2),
recently + Biwer, Bowen, De, Salvesen, GDM, et al

The Lab *could have* played a larger role in first detection

(otherwise I would've gravitated to LANL sooner!)

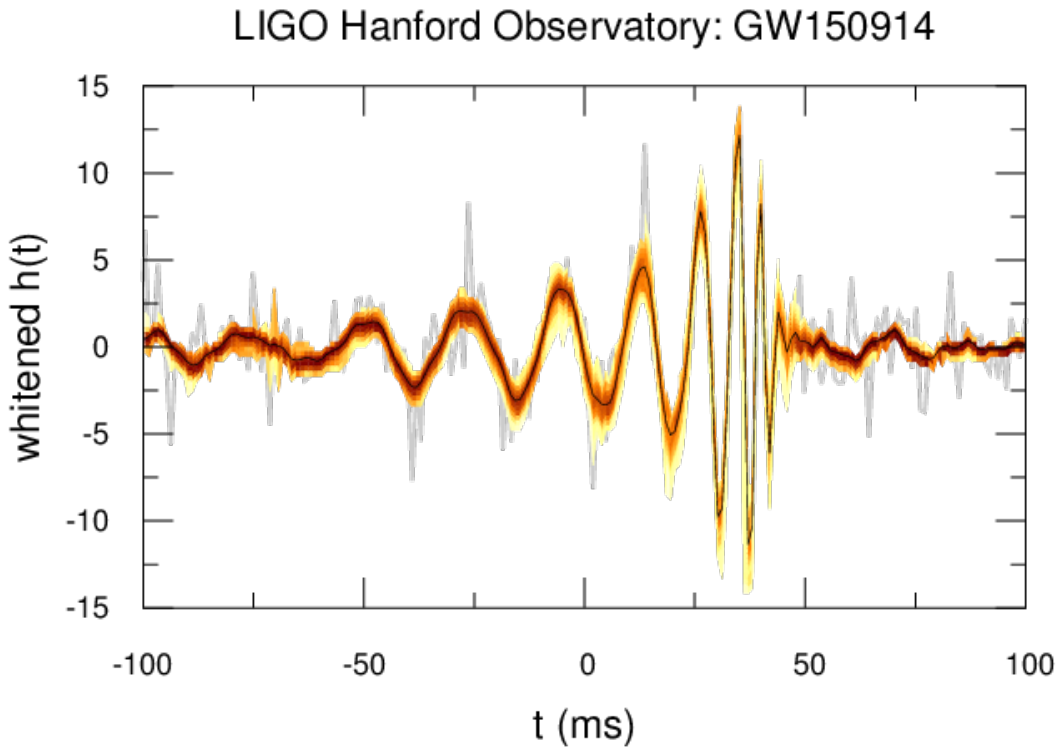
$\rightarrow$ Issue: recruiting + expertise/capability (like Mars attracts people)
$\rightarrow$ Pillar: Science of Signatures [Space]
$\rightarrow$ Pillar: Information, Science, & Technology [Data Science/Computing]

Now is the time to make use of our (currently unfunded)
LISA Consortium membership
$\Longrightarrow$ *Here's how we do that*

What is a Gravitational Wave (GW)?

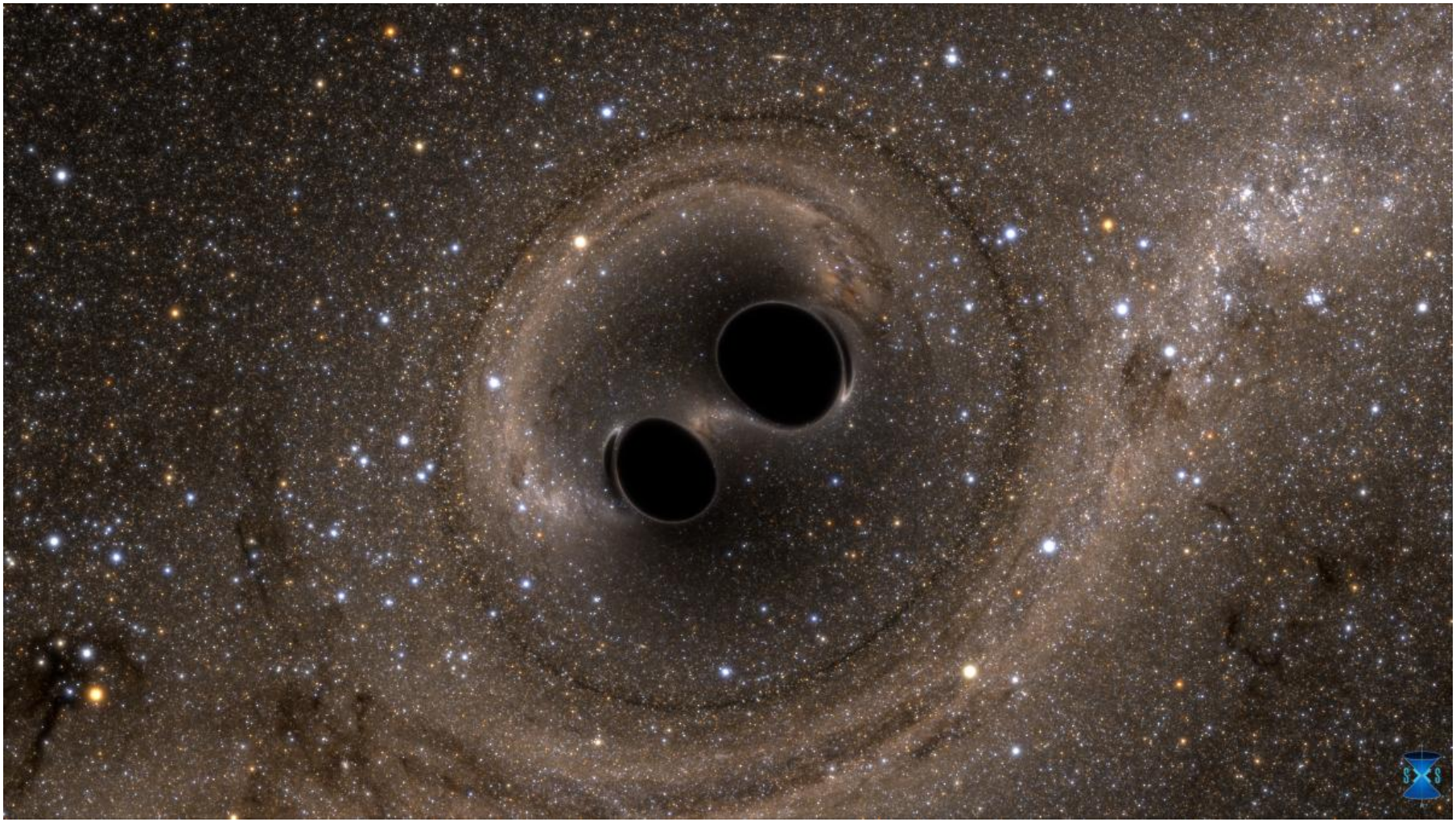
Definition

Oscillations in the metric of space ($>$ 50 mergers seen to-date)



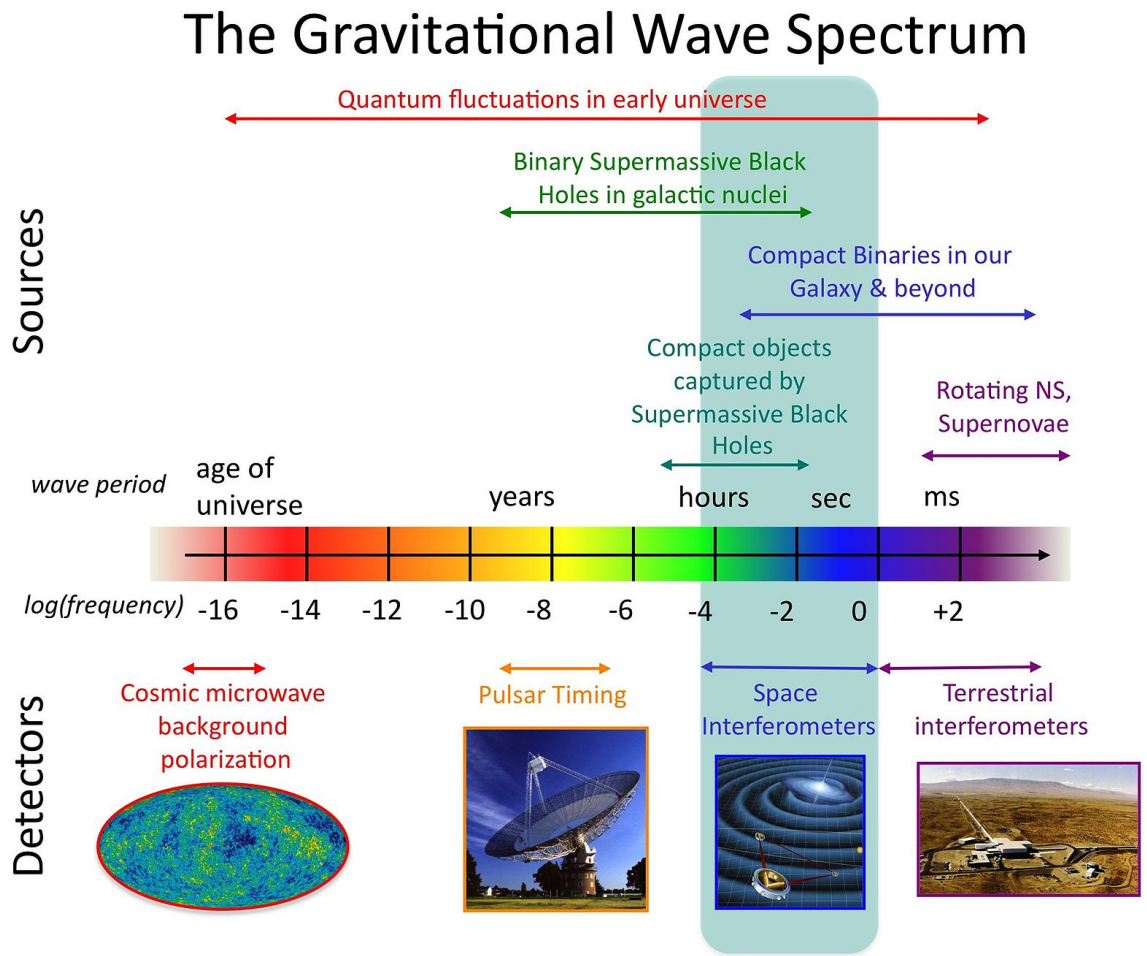
What we woke up to one Monday (credit: LIGO Scientific Collaboration)

What is a Gravitational Wave (GW)?



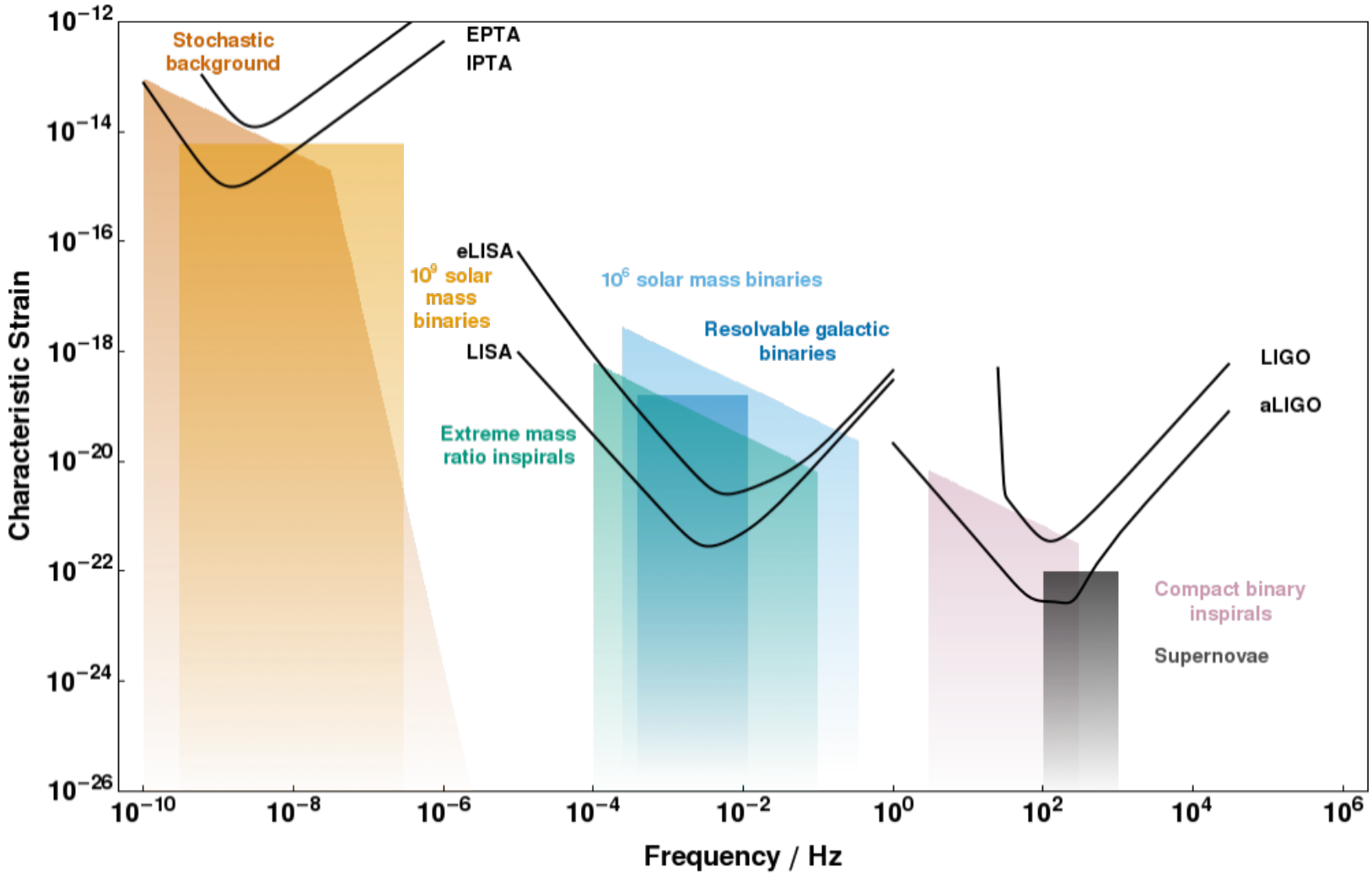
(credit: Simulating Extreme Spacetimes [SXS])

What is a Gravitational Wave (GW)? Spectrum



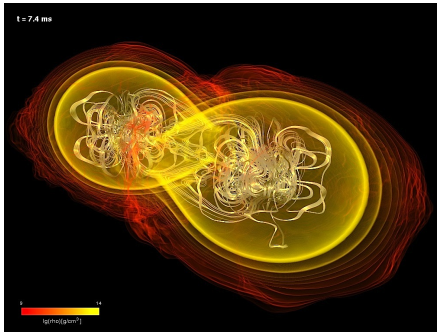
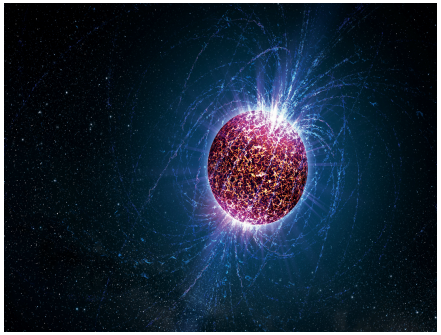
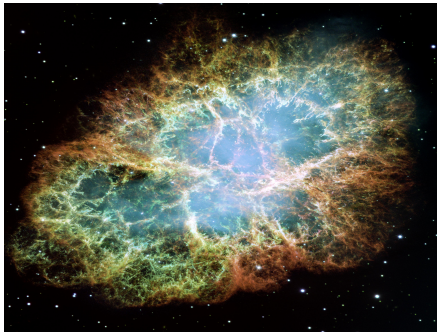
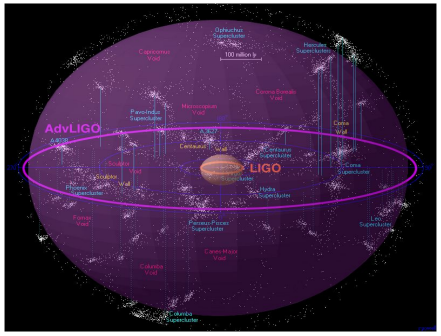
Like light: many λ/f windows (credit: NASA Goddard Spaceflight Center)

What is a Gravitational Wave (GW)? Spectrum



Pulsar-timing/LISA/LIGO sensitivity (credit: C. Moore, R. Cole, C. Berry)

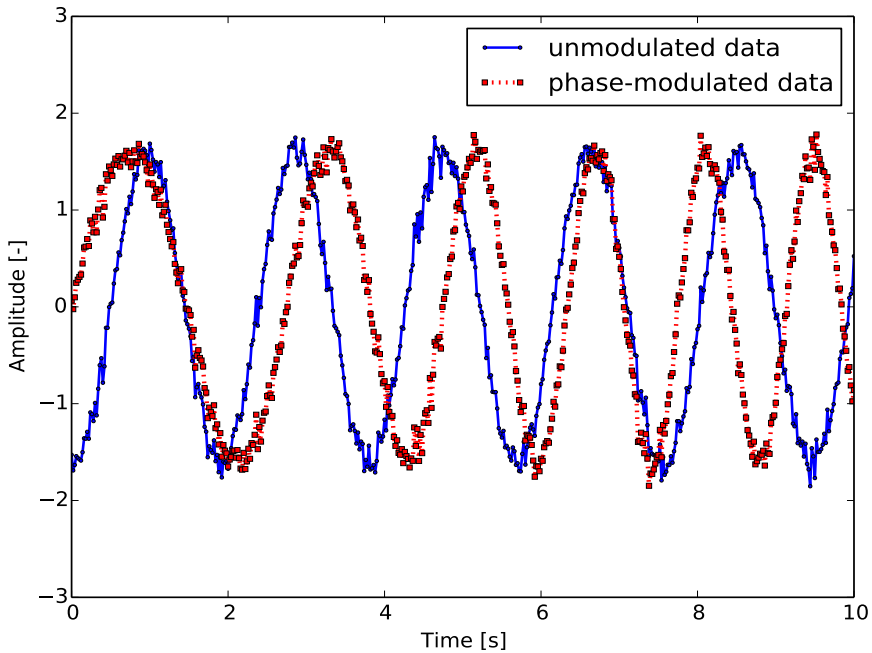
What is a Gravitational Wave (GW)? Sources

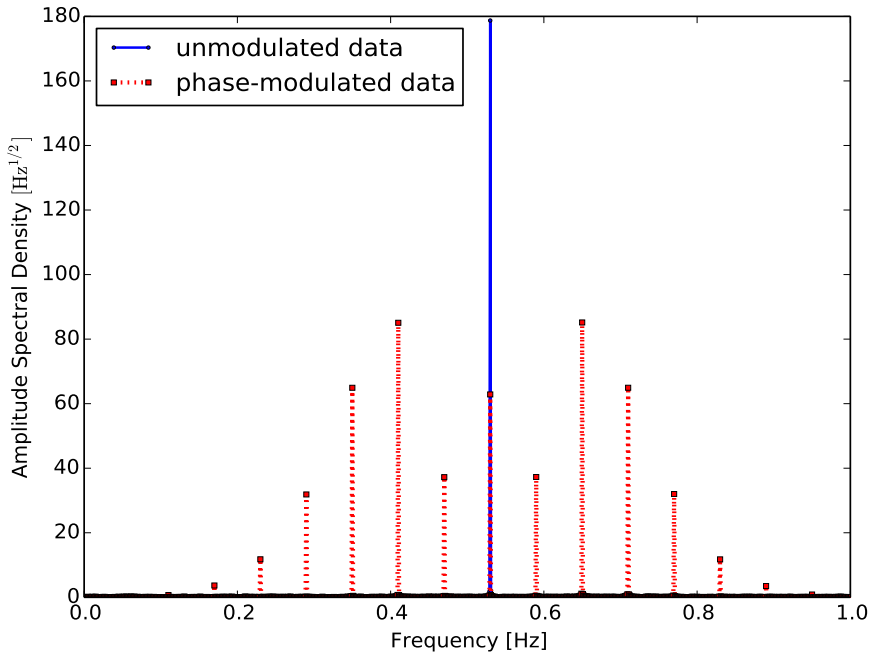
	Transient	*Persistent*
Modeled		
	Coalescence	Continuous ←
Unmodeled		
	Burst	Stochastic

Credits: AEI, Penn State (C. Reed), NASA, LIGO (B. Berger)

What is a Gravitational Wave (GW)? Sources

Phase modulation for long-duration GWs (simplified illustration)



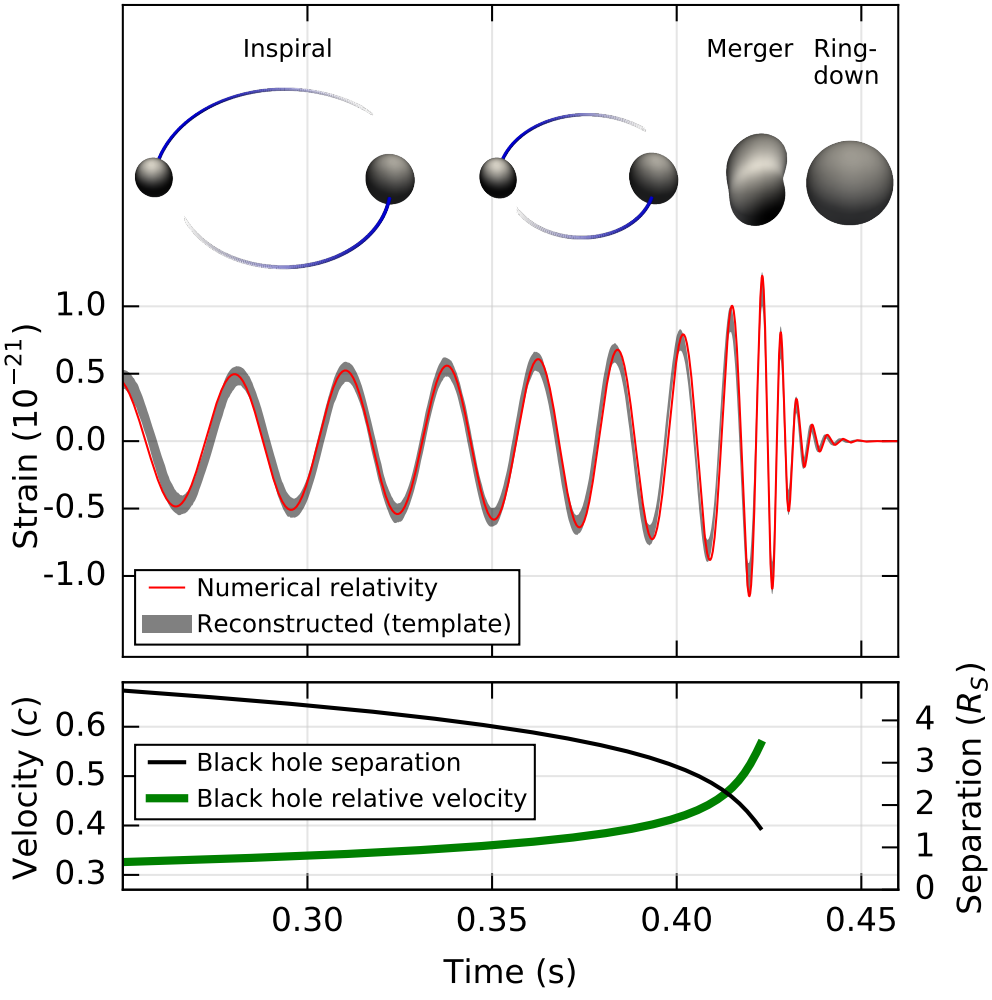


Roemer/Doppler effect from orbit in time & Fourier domains

→ HPC/data-science challenge

(sub-field where I worked most: no detection yet,
but blinded data challenges prove *we have the technology*)

What is a Gravitational Wave (GW)? Sources



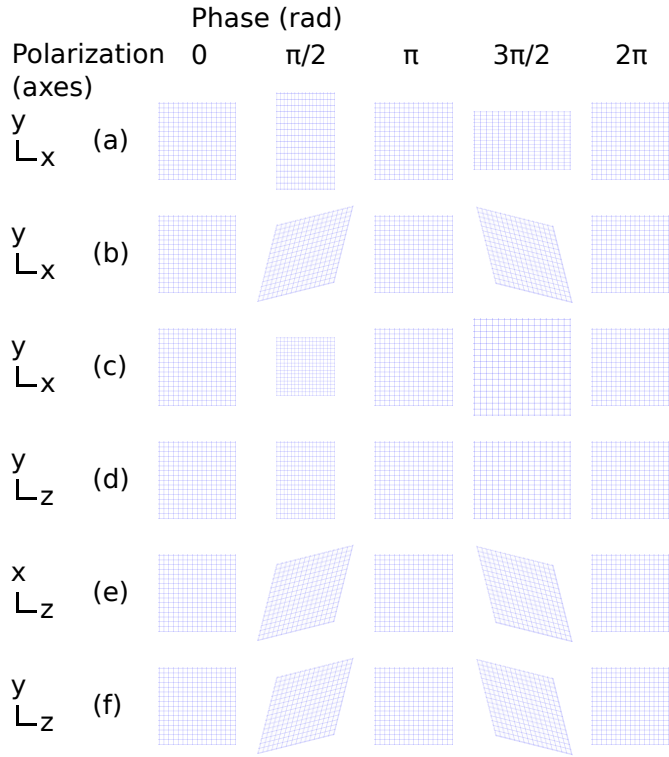
('Observation of gravitational waves from a binary black-hole merger', LVC, *Phys Rev Lett* 116 (2016) 061102)

What is a... (GW)? General Relativity

Wave equation from Einstein: perturbation $h_{\mu\nu}$ to metric $g_{\mu\nu}$,

$$-\frac{1}{2}\partial_t^2 h_{\mu\nu} = 8\pi T_{\mu\nu}$$

$$h_{\mu\nu} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & -h_+ & h_\times & 0 \\ 0 & h_\times & h_+ & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \times \Re\left(e^{i(k_\mu x^\mu + \phi_0)}\right)$$

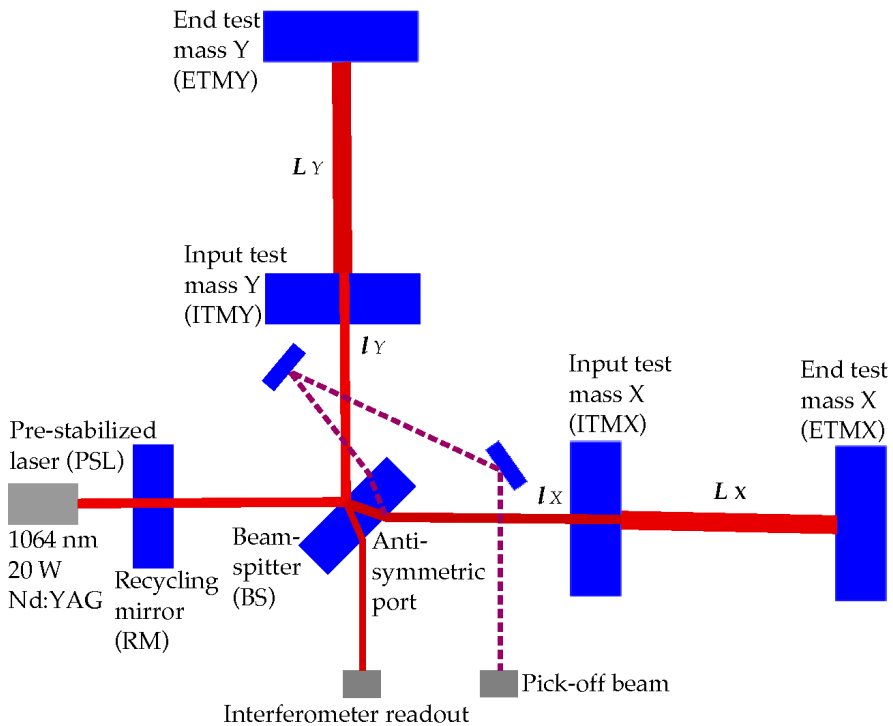


6 theoretical polarizations:
conservation allows only (a) & (b) [+ & $\times$]

What is a... (GW)? Observatories

Infer $h(t)$: *measure* phase ϕ between times-of-flight $T_{x,y}$ (laser ω),

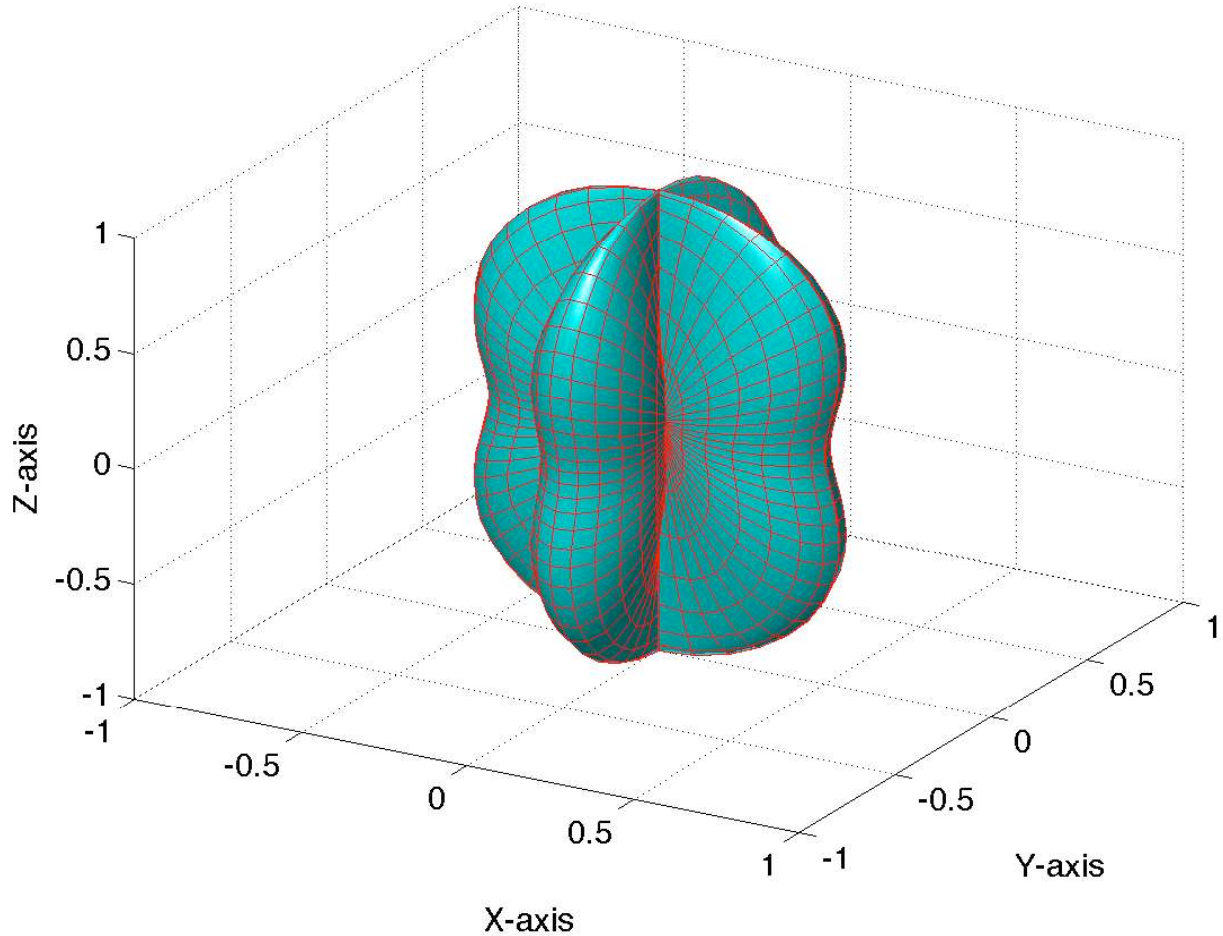
$$\phi \equiv \omega(T_y - T_x) = \omega \int_0^{\frac{2L}{c}} \frac{h_+(t, x(t)) + h_+(t, y(t))}{2} dt.$$



Initial LIGO (1997/2010): Michelson interferometer w/ Fabry-Perot arms

What is a... (GW)? Observatories

Amplitude modulation as Earth rotates (illustration)

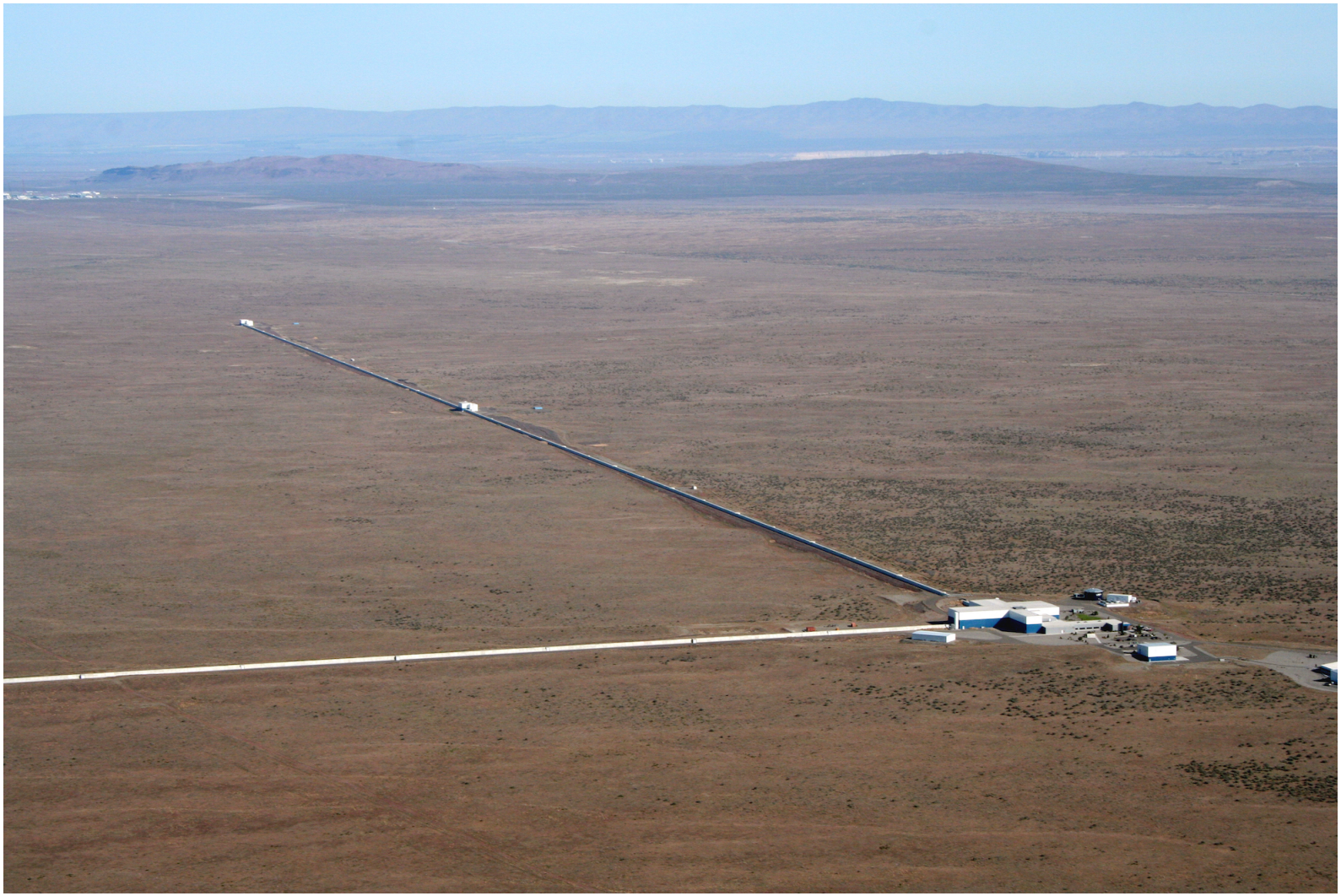


AM: 'Antenna' response, h_+ pol., 0 Hz (credit: M. Rakhmanov)

What is a... (GW)? Observatories

Advanced LIGO: Hanford & Livington (credit: S. Larson, Northwestern U)

What is a... (GW)? Observatories



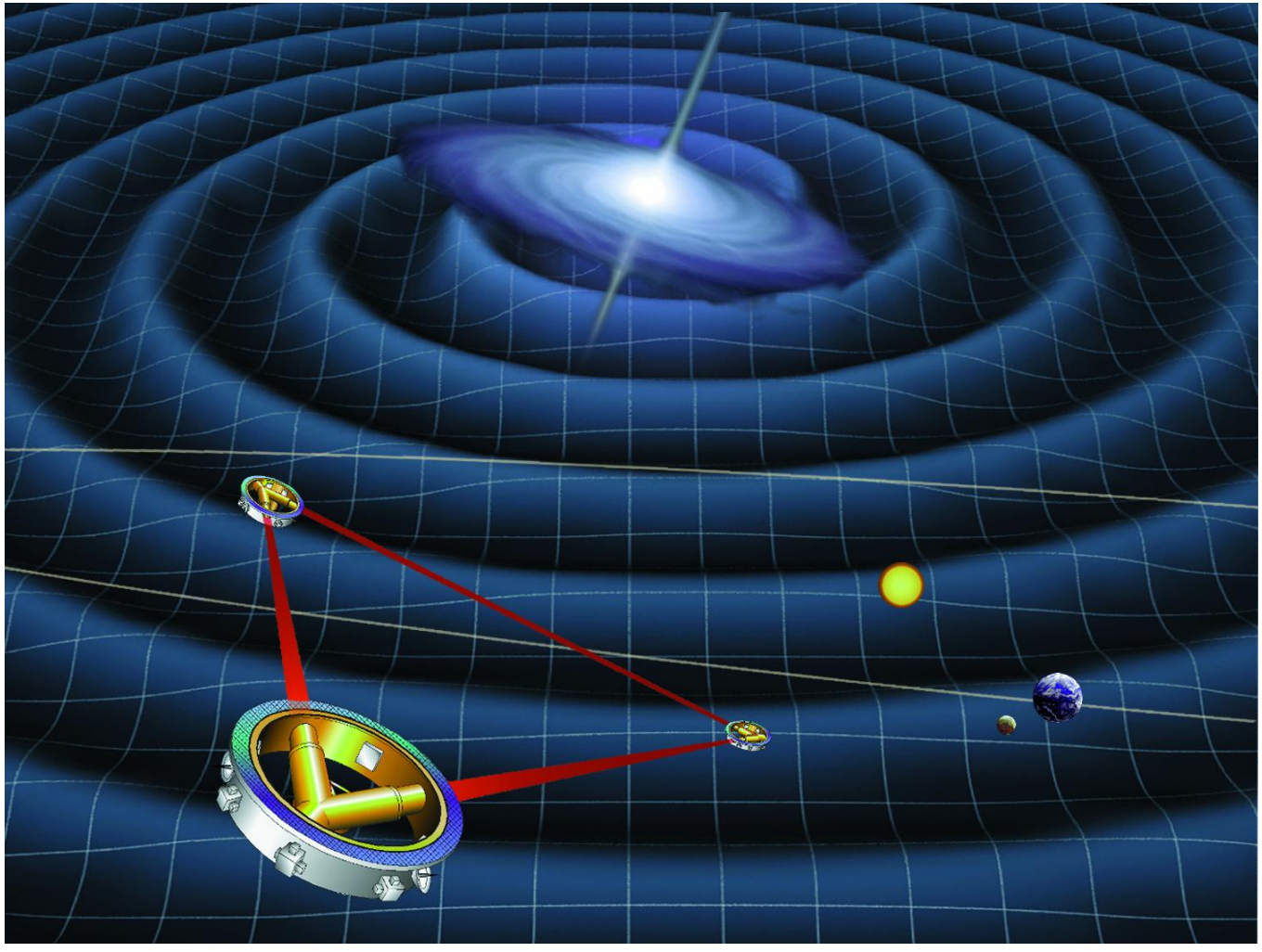
Overlooking X-arm, LIGO Hanford (credit: C. Gray)

Where LISA fits in

Impressions

- Interferometric GW ideas go back to 1960s
  Glasgow/Hughes Lab/MIT/Moscow State;
  First bar detector late 1950s, Joe Weber [Maryland]
- Bigger $=$ (except at high f) better
- Biggest: go to SPACE!

Where LISA fits in



JPL's original plan: 5 Gm, launch $\sim$ 2015. Credit: NASA/JPL

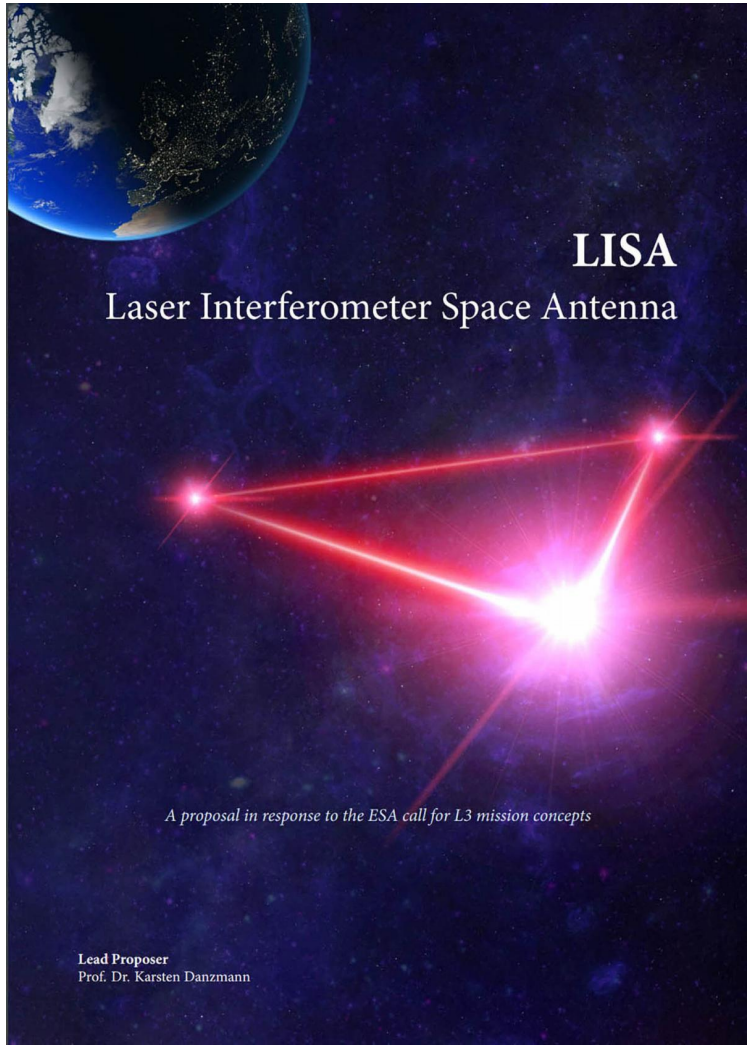
Where LISA fits in

That got cancelled in 2011,... but then ESA stepped in $\Longrightarrow$

selected for L3 misson (2034) in 2017
(following LIGO and LISA Pathfinder)

NASA back onboard

Where LISA fits in



Funded 2017 ESA proposal. Credit: NASA/Simon Barke

Where LISA fits in

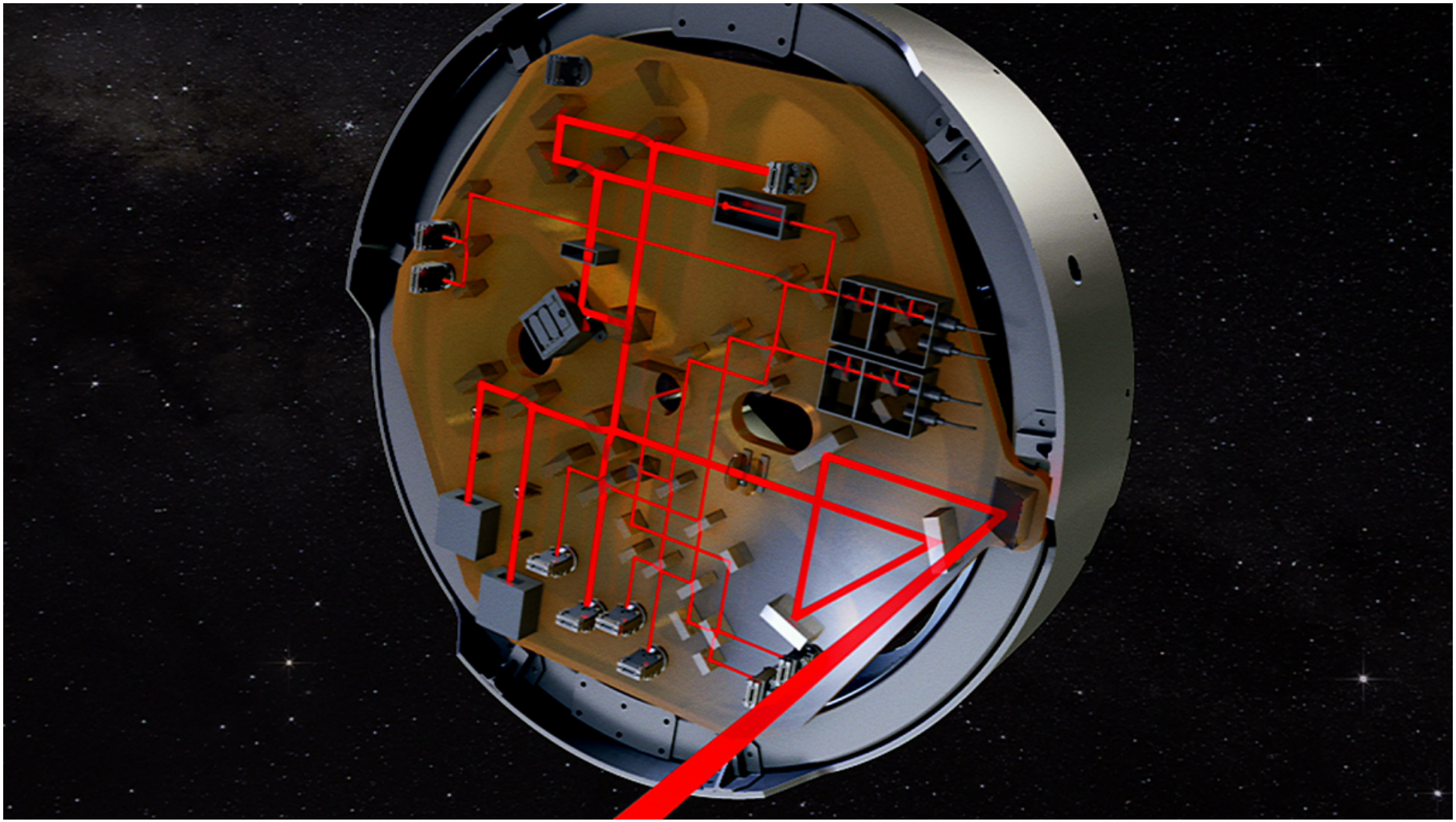
	Advanced LIGO	LISA
Arm length	4 km	2.5 Gm
Laser power	$\sim$ 125 W	$\sim$ 1 W
Interferometry	Michelson	Time-Delay
Resonant Arms	Fabry-Perot	(none)
Recycling	Power+Signal	(none)
Squeezing	$\sim$ 3 dB	(none)
Spectral band	$\sim 10 - 2000$ Hz	$\sim 0.1 - 100$ mHz

Other than being in space,

LISA is a safe, robust design

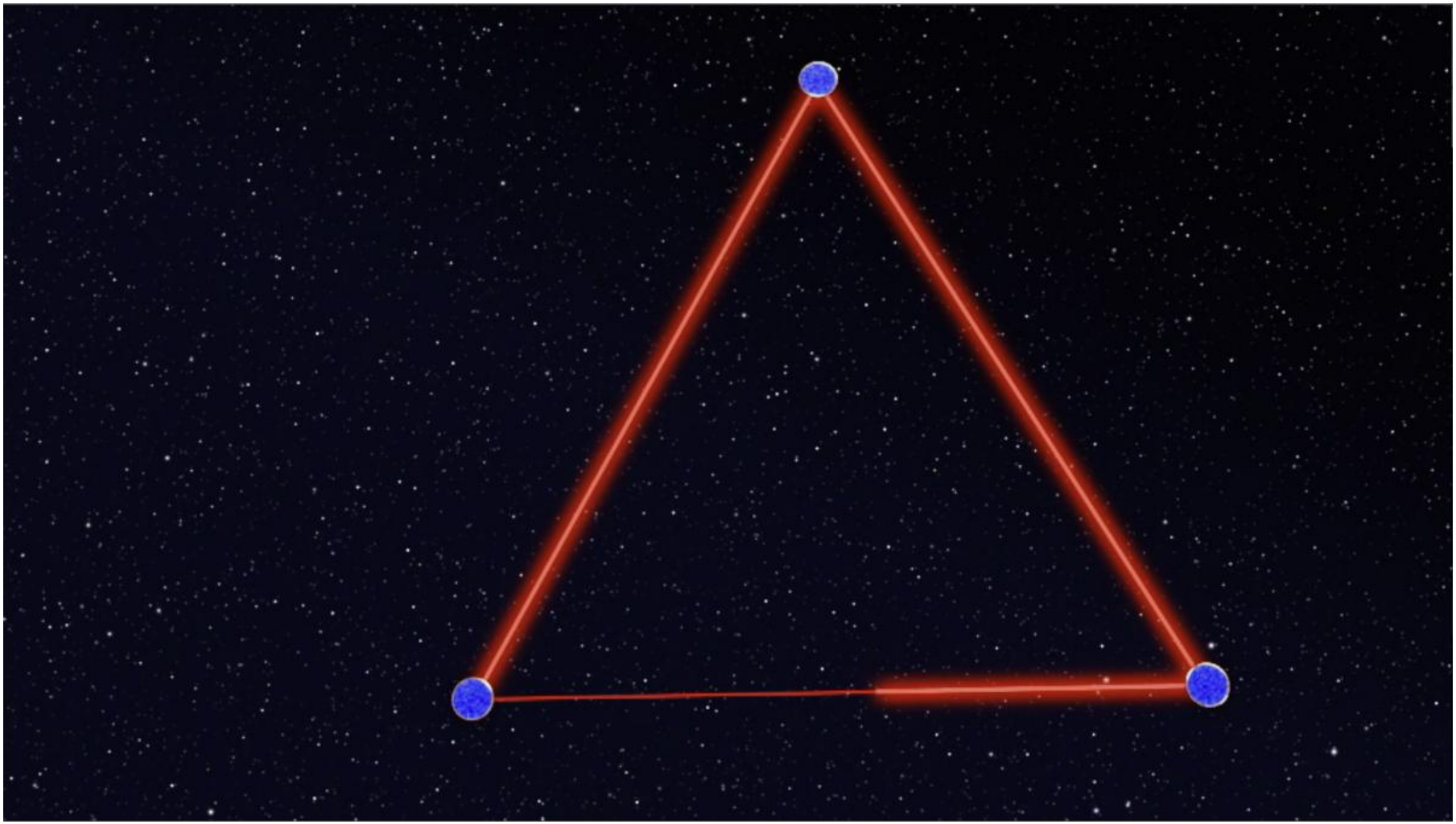
(All that extra stuff is low-hanging fruit for the next-gen)

Where LISA fits in



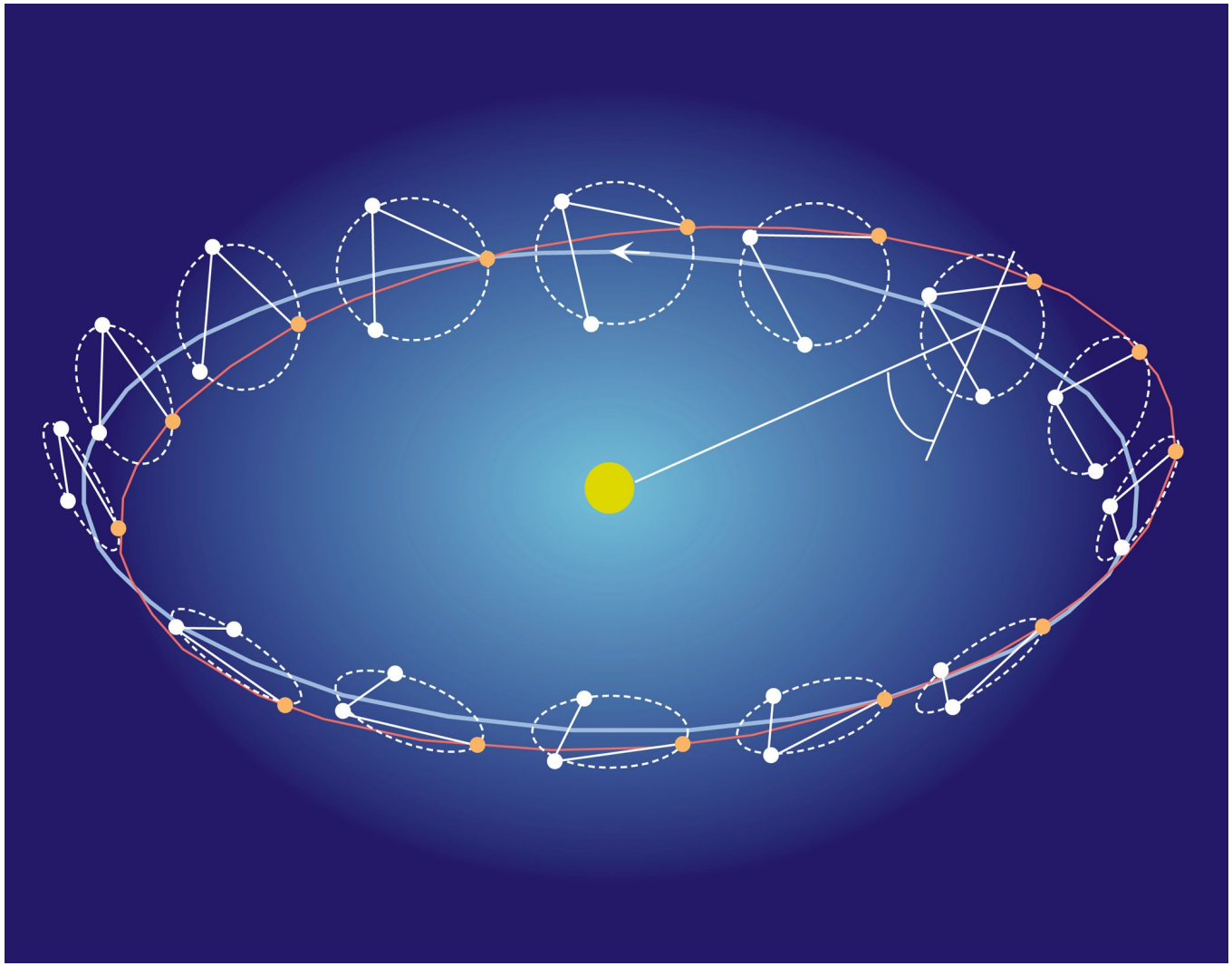
Optical bench in drag-free satellite. Credit: Max Planck/Milde/Exozet

Where LISA fits in



3 arm-pairs $\rightarrow$ polarization. Credit: Max Planck/Milde/Exozet

Where LISA fits in



Satellites (triangular formation) in heliocentric orbit. Credit: ESA

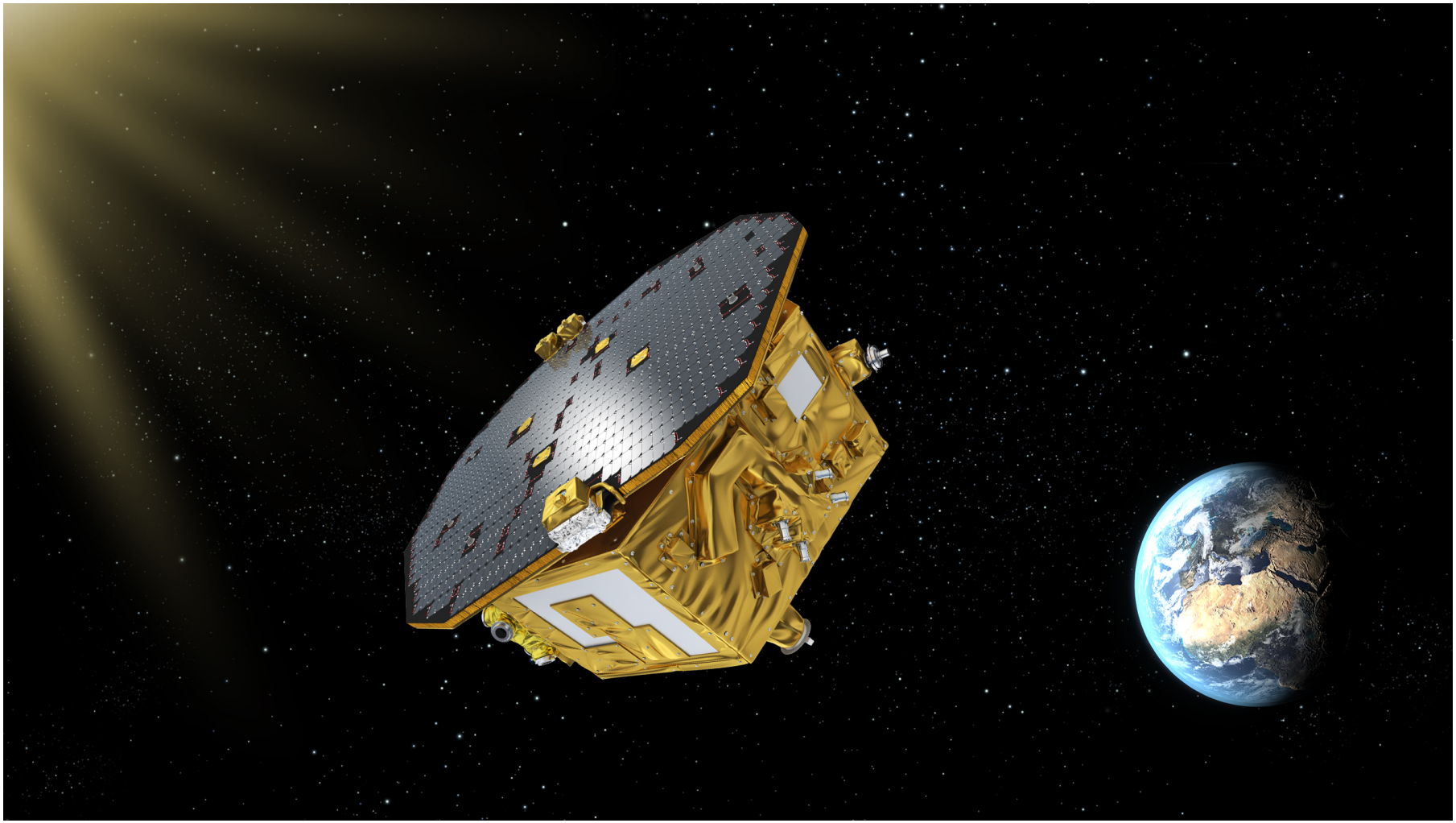
Where LISA fits in

Seem ambituous...

is it technologically ready?

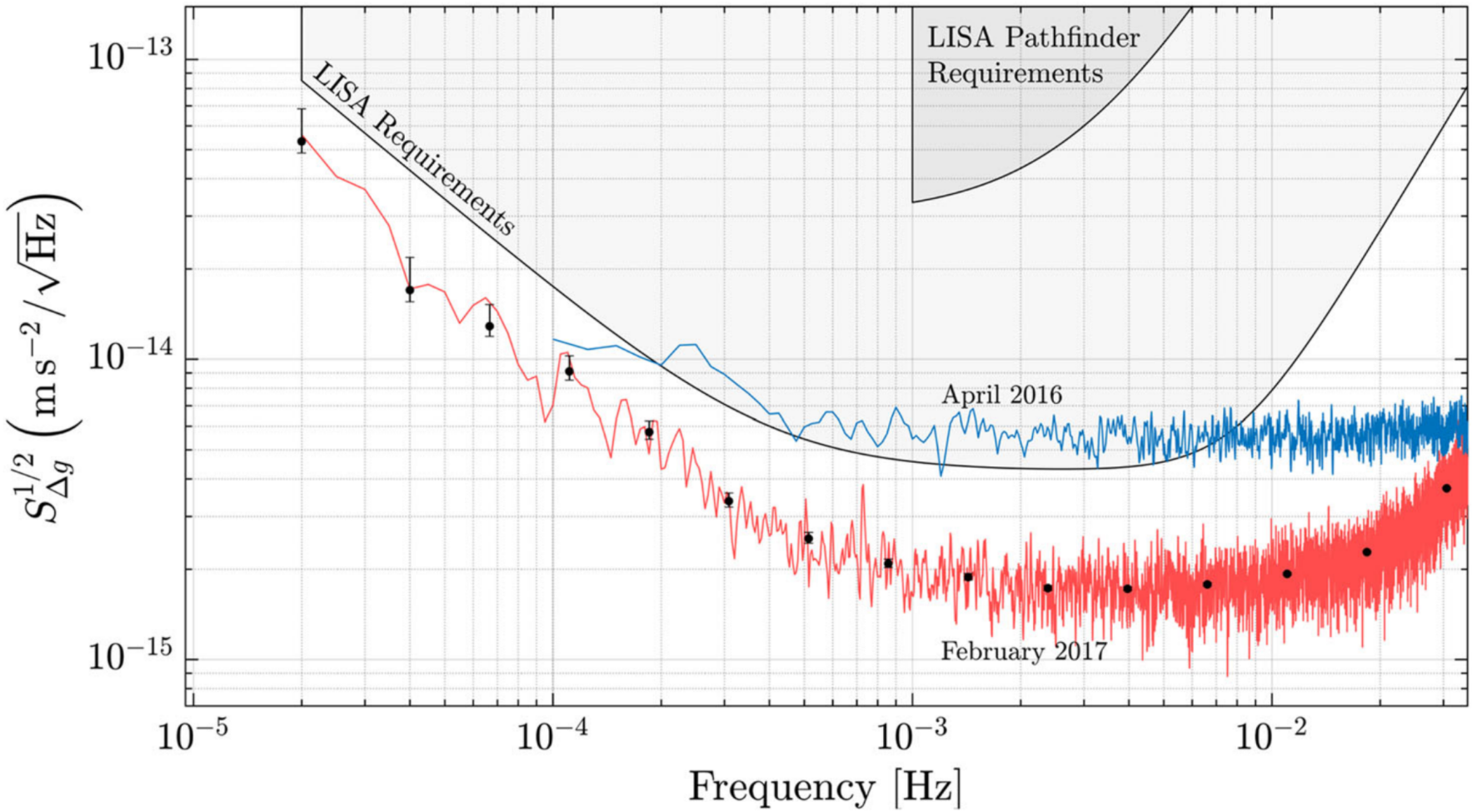
YES

Where LISA fits in



LISA Pathfinder, launched 2015. (Credit: ESA, C. Carreau)

Where LISA fits in



Success! Credit: ESA, c.f., Fig 1, Armano et al, PRL 120, 061101 (2018)

Why LISA benefits LANL

→ Issue: recruiting + expertise/capability (like Mars attracts people)
→ Pillar: Science of Signatures [Space]
→ Pillar: Information, Science, & Technology [Data Science/Computing]

Why LISA benefits LANL

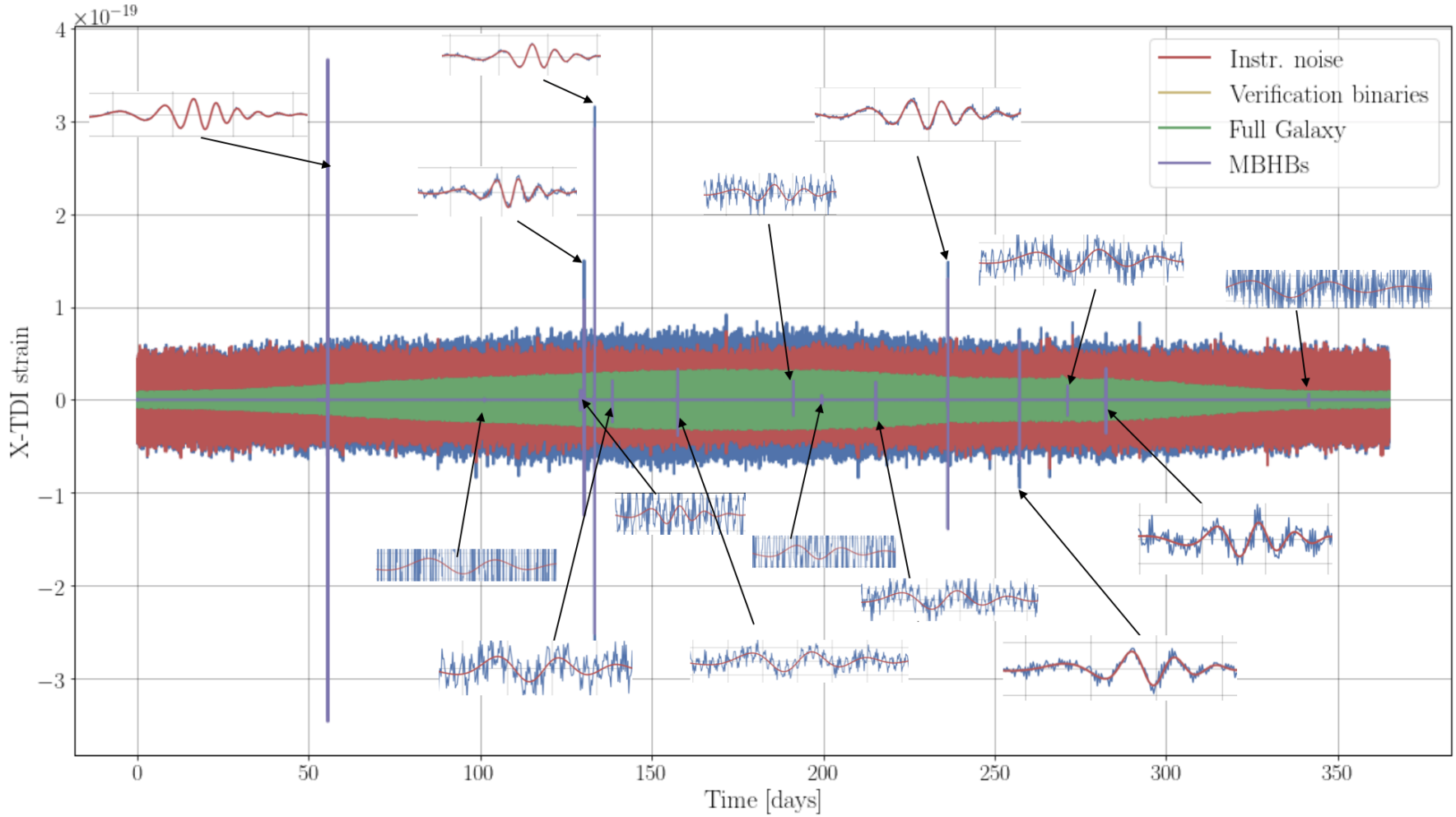
Placing LISA in a larger context

- GRACE Follow-on (geodesy mission)
- Tianqin (possible white-dwarf detection, 2020s)
- Past LANL-NASA partnerships (e.g., ChemCam) of similar scale
- Need to build pipeline into Lab
- Open science expertise key to skill/capability development

How you can get involved

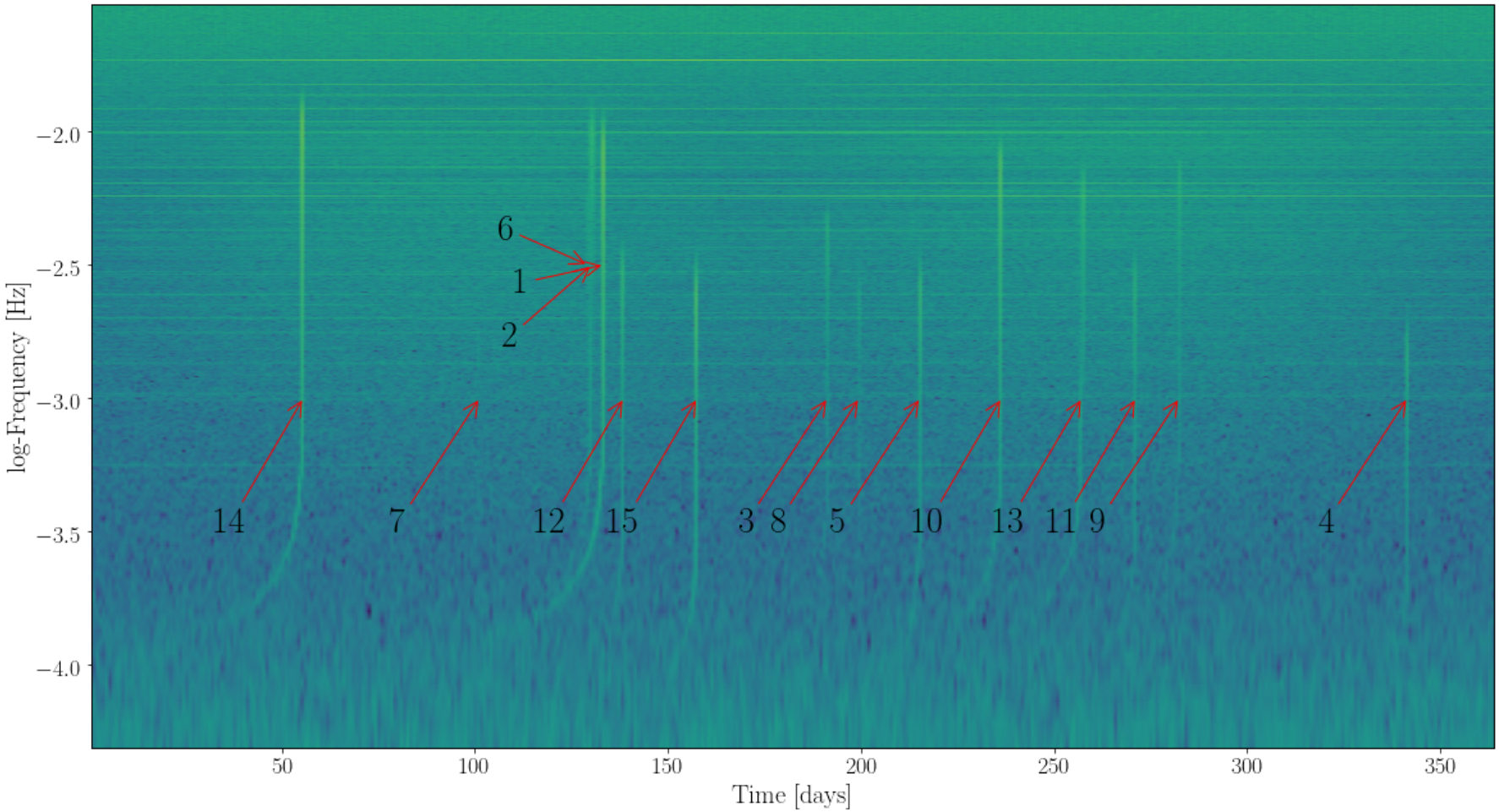
Sign up! Telecons & emails for all! Credit: LISA Consortium

How you can get involved: right now



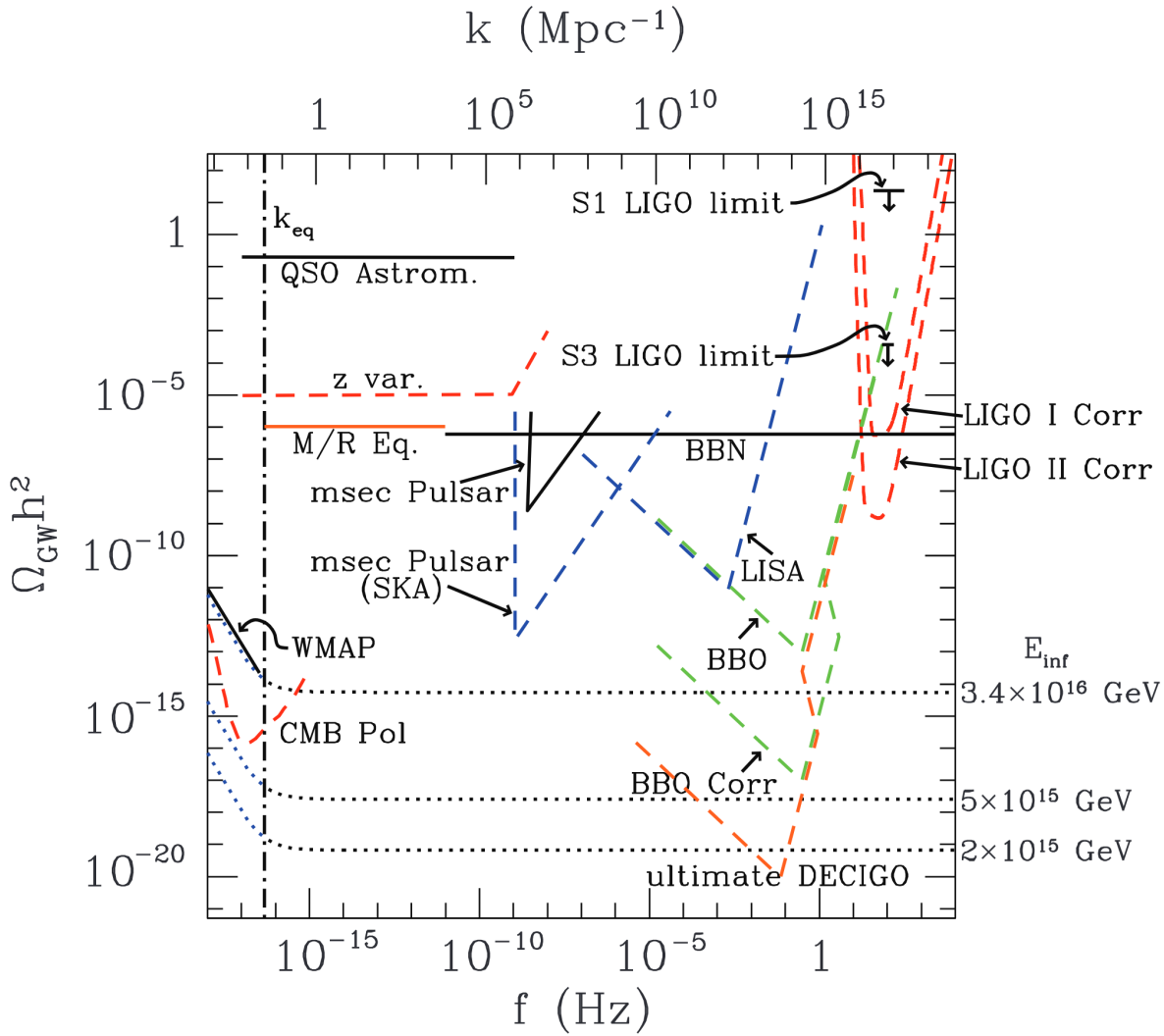
Simulated dataset w/ signals. Credit: LISA Data Challenge, C. Cavet

How you can get involved: right now



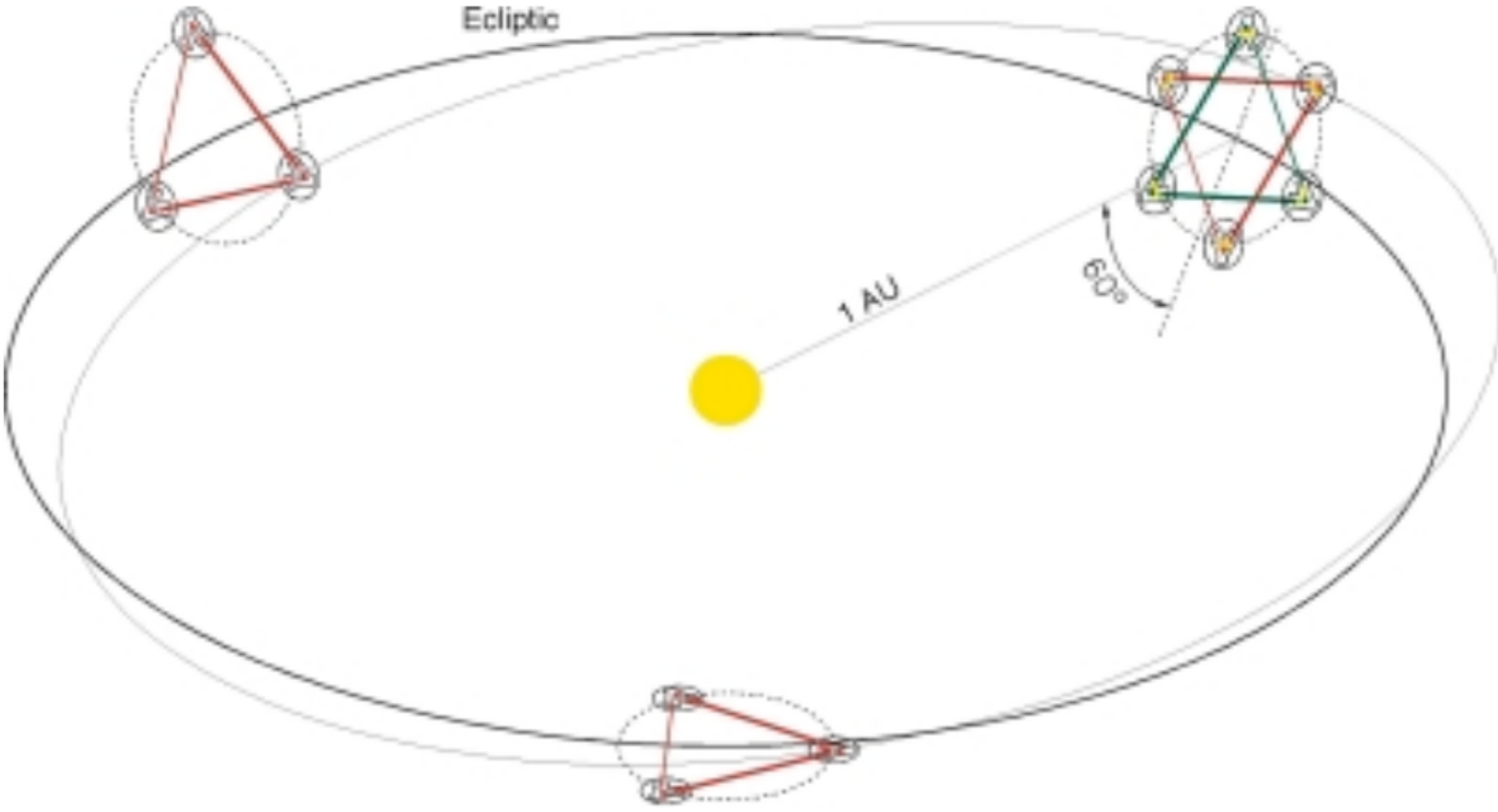
Periodogram of simulated data. Credit: LISA Data Challenge, C. Cavet

How you can get involved: the future



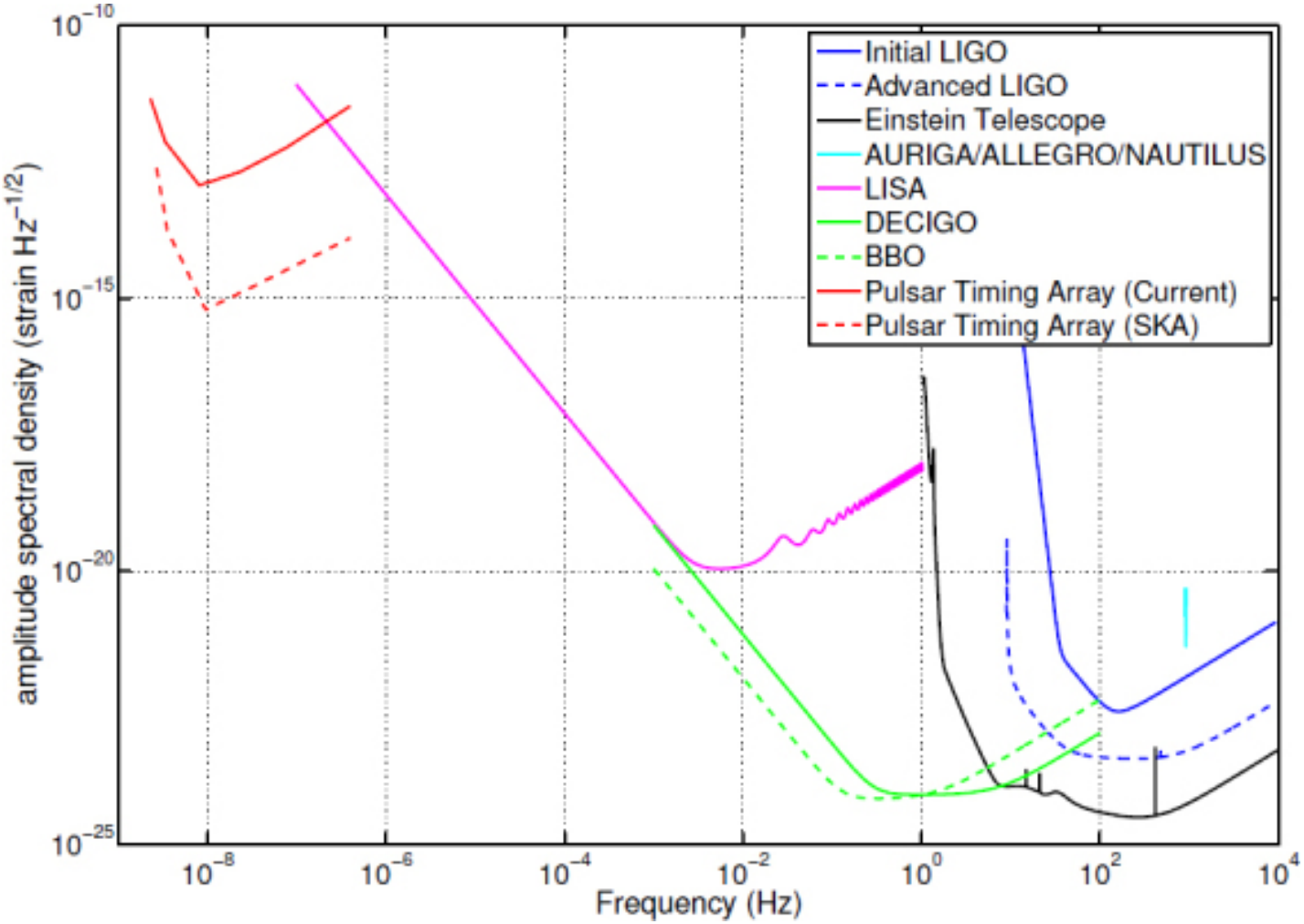
Inflation/strings. Credit: Fig. 1, Smith et al, arXiv:astro-ph/0506422v2

How you can get involved: the future



12 sats in 3 sets. Credit: Fig. 3, Folkner & Seidel, Space 2005, p. 6711.

How you can get involved: the future



Beyond LIGO/LISA! Credit: Fig. 1, Liv. Rev. Rel. 14 (2011) 5, Pitkin et al.

How you can get involved: the future

LANL people already involved/interested

- Chris Fryer (CCS-2),
  organizer for Center for Theoretical Astrophysics,
  LISA point of contact
- Robert Hill (ISR-2),
  interested in galactic structure
- Jarrett Johnson (XTD-DO),
  earliest black-hole (BH) formation
- Alexander Kalterborn (CCS-2),
  researching white dwarf-neutron star waveforms,
- Hyun Lim (CCS-2),
  modeling binary white dwarf background & IMBH waveforms,
- GDM (ISR-3), listening on calls, planning data analysis strategy,
- . . . and soon others

How you can get involved: the future

Funding *... is the biggest obstacle*

- Planning LDRD-ECR next year
- LDRD-ER or -DR reasonable in next few years
- CSES has funding for proposal development
  (point of contact: Lisa Danielson)
- NASA **LISA Preparatory Science Program** grants
  next due date: December 15 (c.f., ROSES-2020)

Conclusion

Let's work together!

- LISA is the *next generation* of (GW) astronomy
- LANL needs to *attract* & *retain* talent w/ public-facing science
- ISR can gain skills: *data* in **LISA**, *instrument* in **BBO**

Acknowledgments
Thanks to Keith Morgan for organizing the ISR-3 Brownbag Seminar Series, as well as my colleagues in the Data Science Team for welcoming me this year.
This work is assigned LA-UR-21-xxxxx.

Questions: gdmeadors@lanl.gov